Project Scientist Report

Presented by
Nicholas White (GSFC)

207th Meeting of the American Astronomical Society
January 8 – 12, 2006/Washington, D. C

The Constellation-X Mission

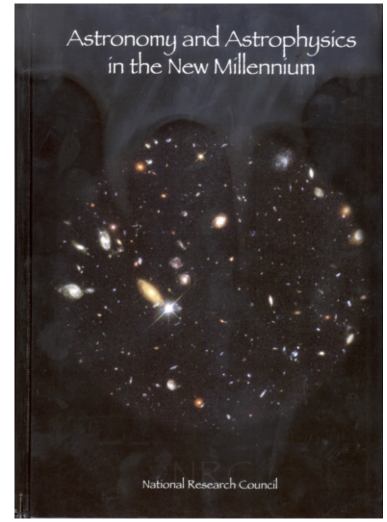
Science Goals:

- Black Holes
  - Probing strong gravity
  - Evolution & effects on galaxy formation
- Dark Matter and Dark Energy
  - Cosmology using clusters of galaxies
- Cycles of Matter and Energy
  - Cosmic feedback, extreme states of matter, stellar coronae, supernovae, planets, etc..

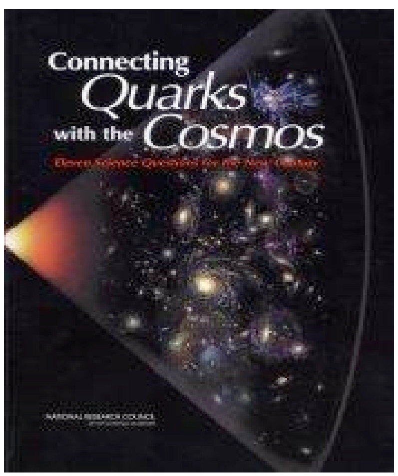
A Constellation of X-ray telescopes for high resolution spectroscopy:

- 25-100 times gain in throughput over current missions
- Major facility that will open a new window for X-ray spectroscopy
- Four spacecraft orbiting around the L2 point, pointing at the same target with the data combined on the ground

Science Priority



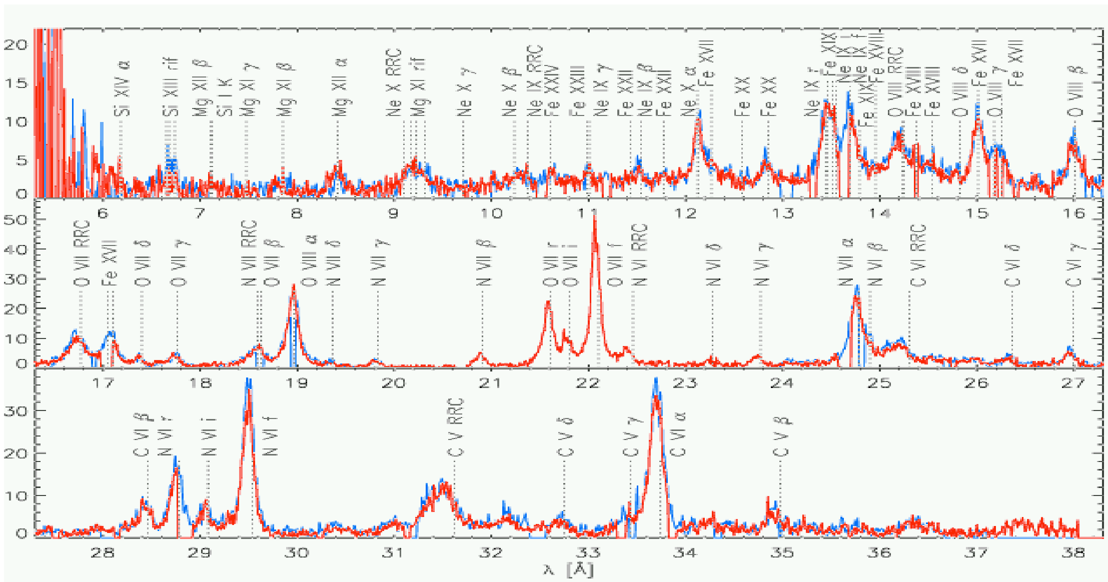
The Astronomy and Astrophysics in the New Millennium “decadal survey” ranked Constellation-X next priority to the JWST for large new space observatories



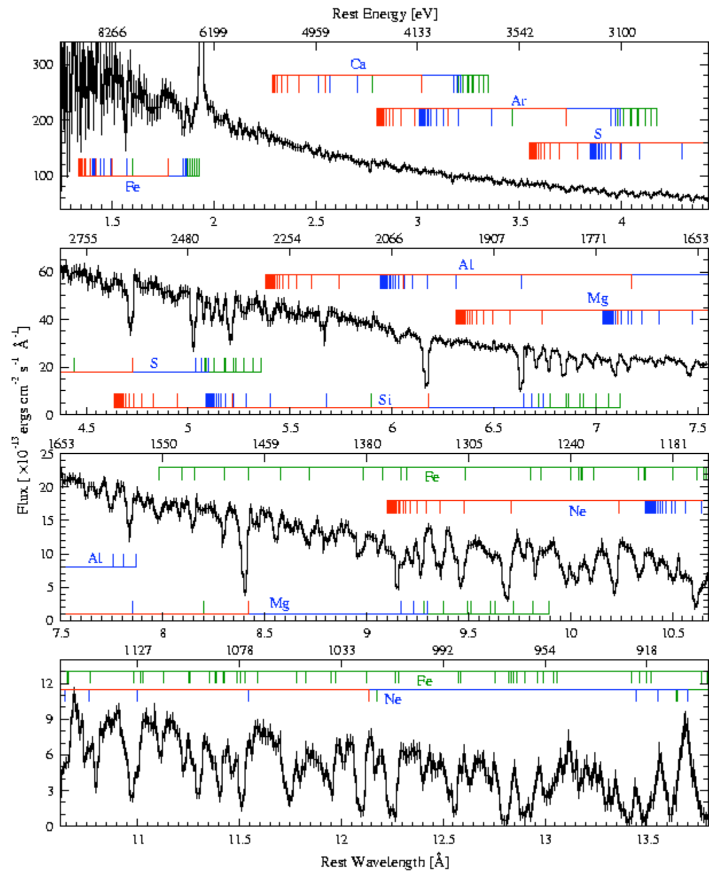
The National Academy Committee chaired by Michael Turner prepared a science assessment and strategy for research at the intersection of Physics and Astronomy strongly endorsed the Constellation-X mission

A Glimpse of the future

Heroic Grating observations from Chandra and XMM-Newton are providing the first glimpse of the power of X-ray Spectroscopy



XMM RGS Spectrum of NGC1068 Kinkhabwala et al 2002



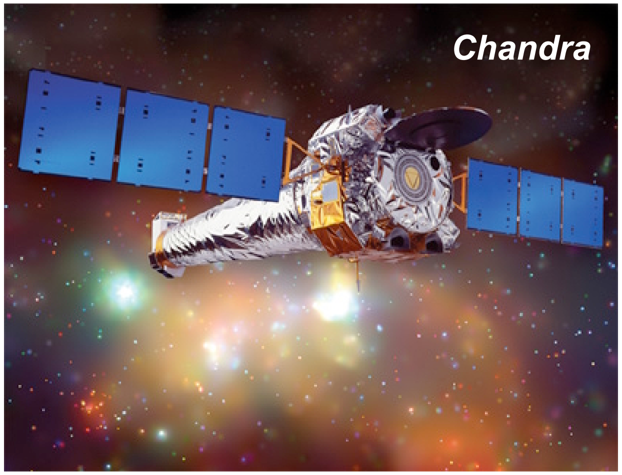
Chandra HETGS Spectrum of NGC3783 from Kaspi et al (2002)

Constellation-X will be able to observe sources 100 times fainter to exploit these diagnostics on typical X-ray sources.

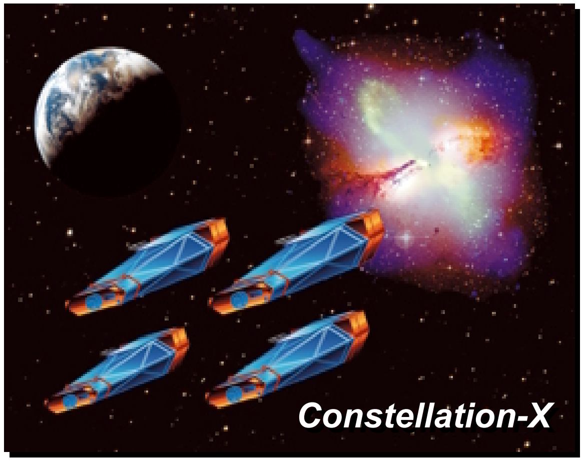
Facility for High Throughput X-ray Spectroscopy

Constellation-X provides high throughput, high spectral resolution, & broad energy bandpass

Large sample sizes of key astrophysical objects



The spectroscopy of Constellation-X compliments the superb imaging of Chandra, in a manner similar to the way the Keck and Gemini compliment HST

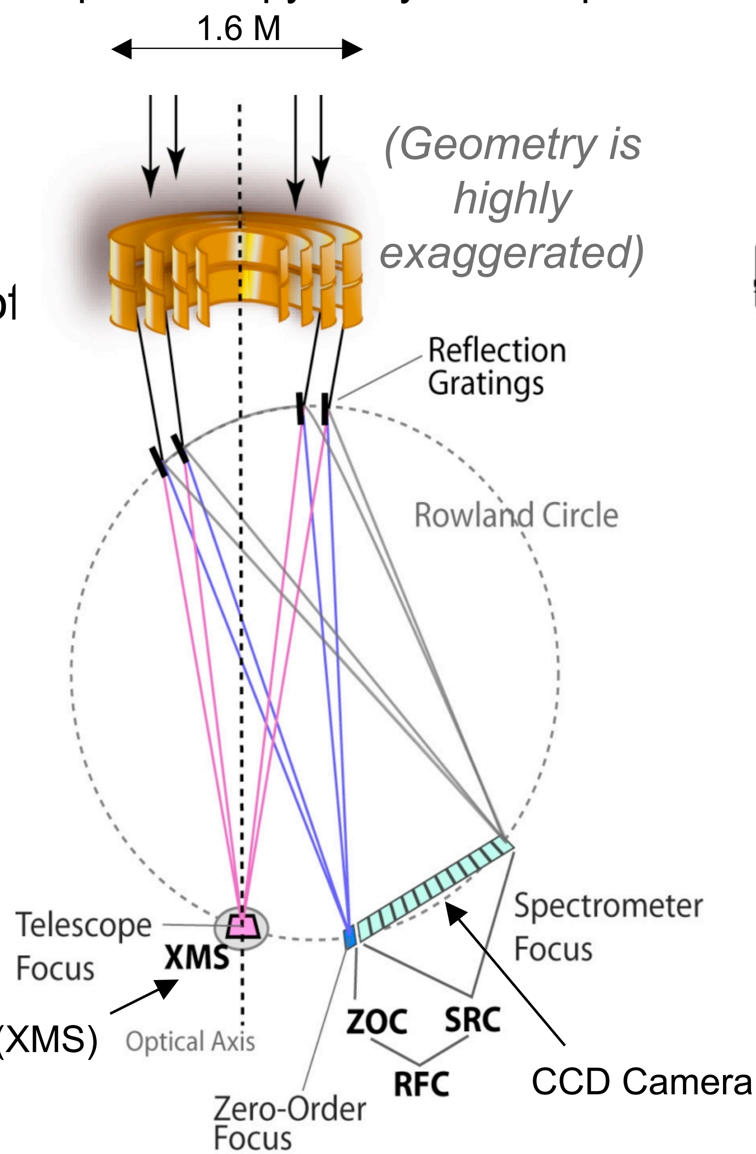


Constellation-X Payload

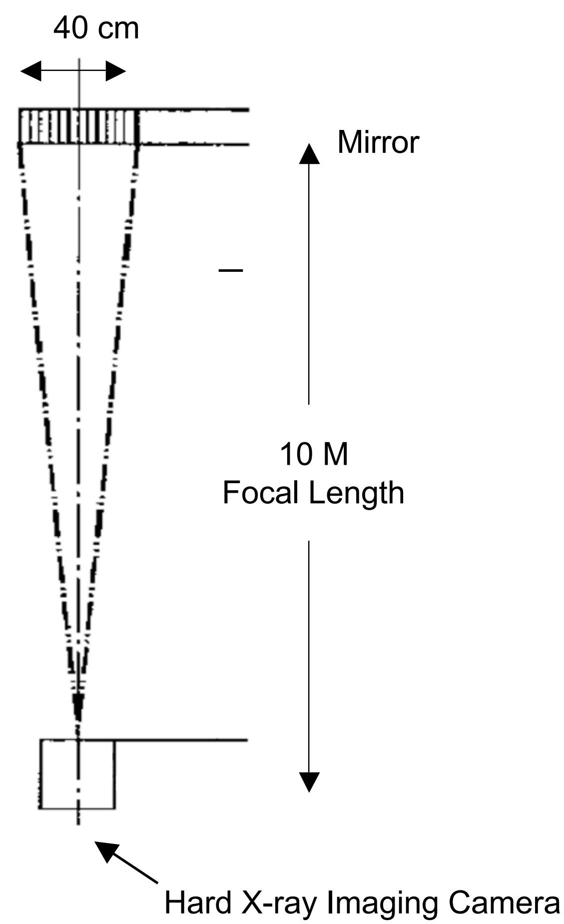
Baseline configuration of 4 SXT and 12 HXT divided across four spacecraft

All instruments operate simultaneously

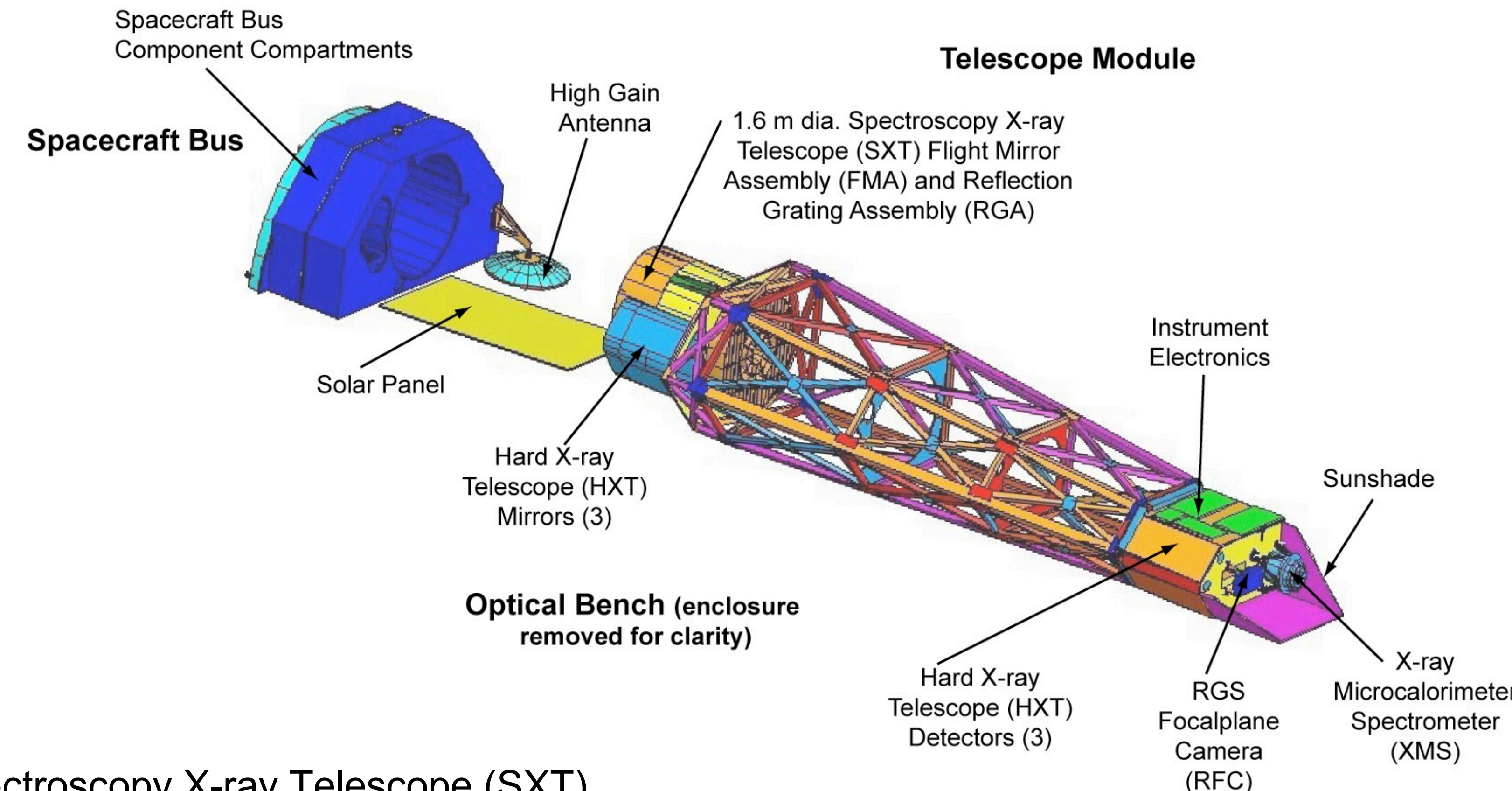
Spectroscopy X-ray Telescope



Hard X-ray Telescope



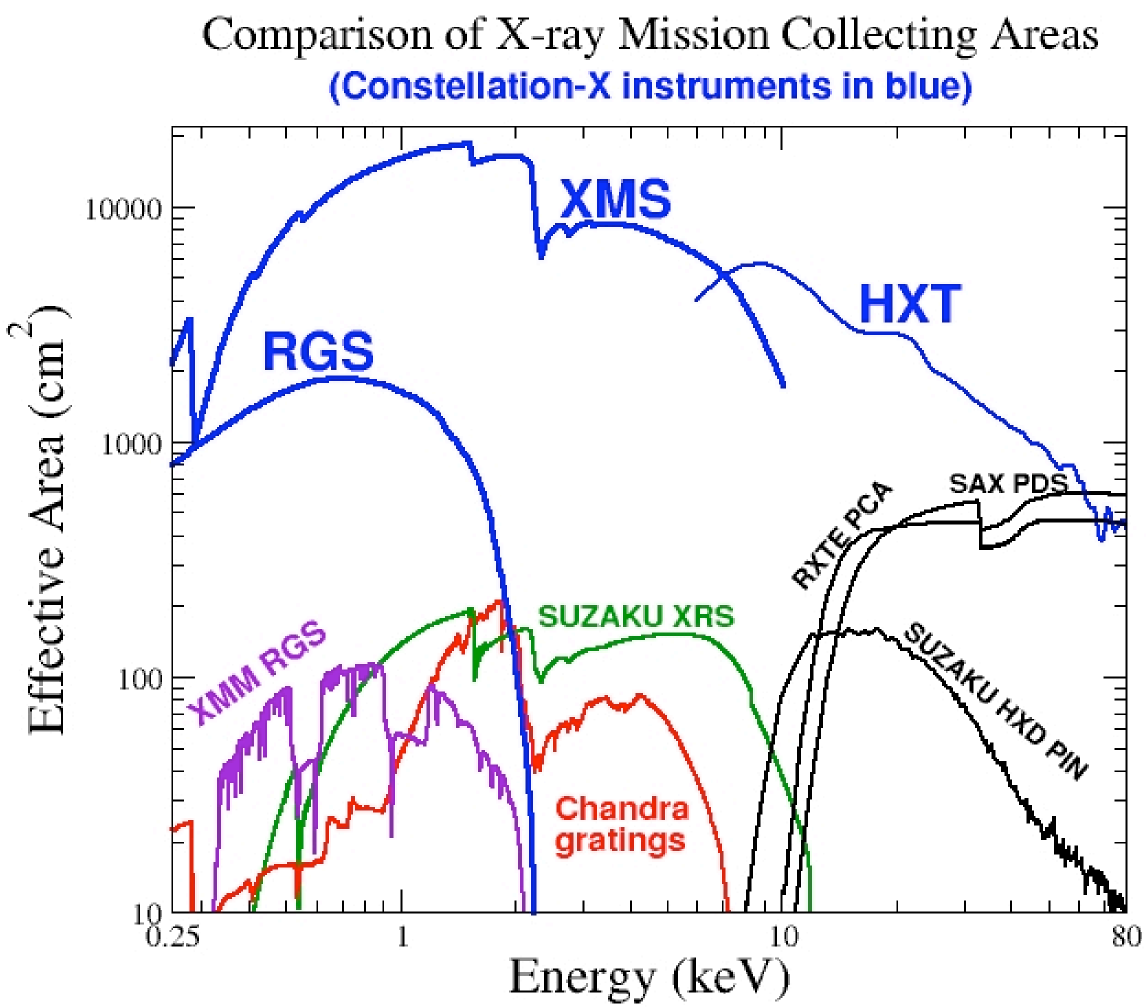
View of Observatory



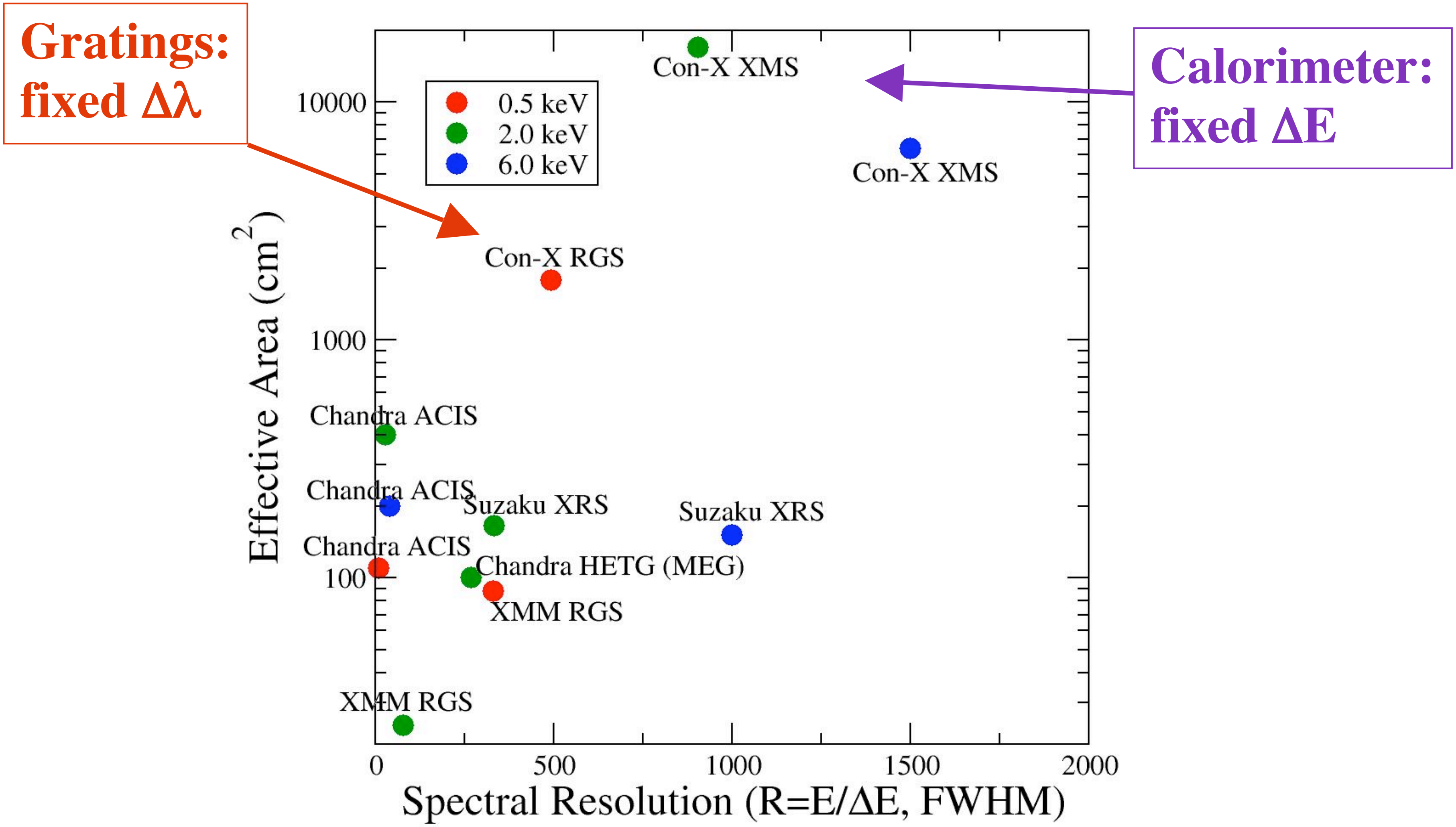
Spectroscopy X-ray Telescope (SXT)
Hard X-ray Telescope (HXT)
SXT consists of a single mirror assembly (SXT FMA) shared by two instruments
- Reflection Grating Spectrometer (RGS)
- X-ray Microcalorimeter Spectrometer (XMS)

HXT consists of 3 mirror assemblies, each with a detector at its focus

Comparison of collecting area



Collecting area vs. Spectral resolution



Key Constellation-X Capabilities

- A factor of 25-100 increased collecting area for E/DE ~ 300 to 1500 spectroscopy
- Routine spectroscopy to a flux of 2 x 10^{-15} ergs cm^{-2} s^{-1} (0.1 to 2.0 keV), with 1000 counts in 100,000s
- Factor ~100 increased sensitivity in 10 to 40 keV band
- New velocity diagnostics that with a DE of 4 eV at 6 keV gives a bulk velocity of 200 km/s & centroiding to an absolute velocity of 20 km/s
- SXT angular resolution requirement of 15 arc sec HPD, 5 arc sec goal
- Field of View 2.5 x 2.5 arc min with 32 x 32 pixels
- Ability to handle 1,000 ct/sec/pixel

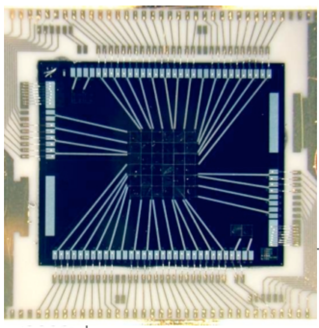
Mission Update

1. Loss of Suzaku X-Ray Spectrometer (XRS) leaves major gap and the promise of micro-calorimeter technology unrealized until Constellation-X
2. Constellation-X is an extension of heritage technologies and development continues to progress well, with excellent leverage off the R&A program (see Garcia talk)
3. Science case recently updated and reaffirmed (see Hornschemeier talk)
4. Single Delta IVH instead of two Atlas IV launchers under study that may reduce mission cost while maintain science capability
5. Technology solicitation expected in the Spring 2006
6. Mission Status:
   – End to end cost: $2.5B (Real Year dollars including inflation) or $1.6B (Constant Year 2000 dollars)
   – Launch date is currently no earlier than 2017/18, and is driven by budget constraints - not technology or schedule

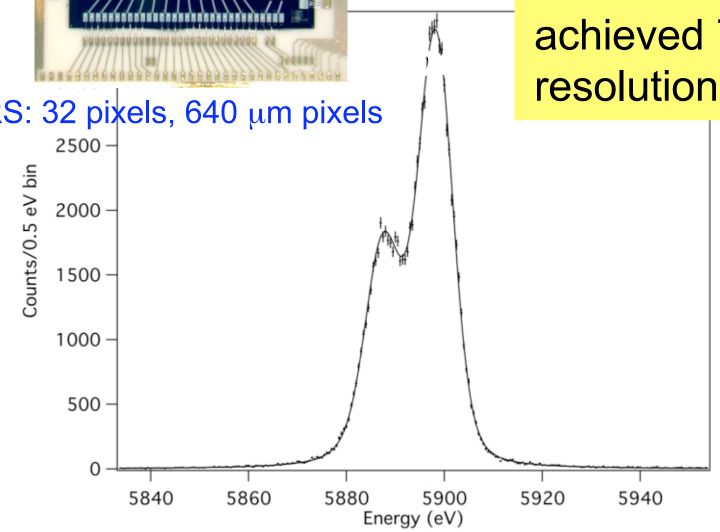
X-ray Micro-calorimeters

Thermal detection of individual X-ray photons gives a 20-40 increased spectral resolution over the Chandra CCDs

Arrays have been successfully demonstrated on sounding rockets and now *Suzaku* (Astro-E2)

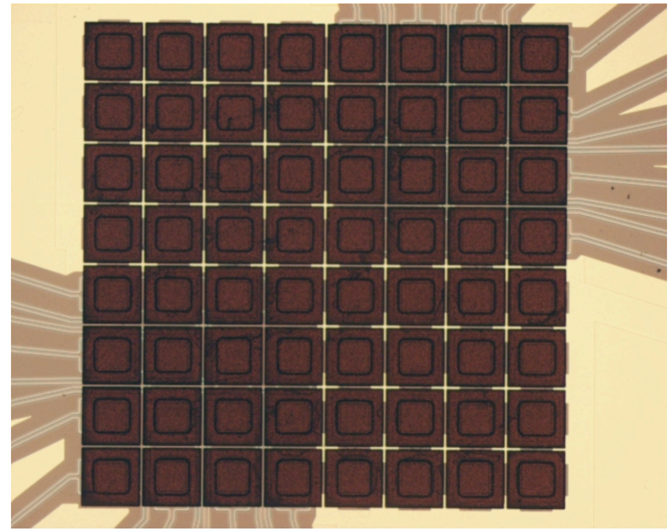


XRS: 32 pixels, 640 μm pixels

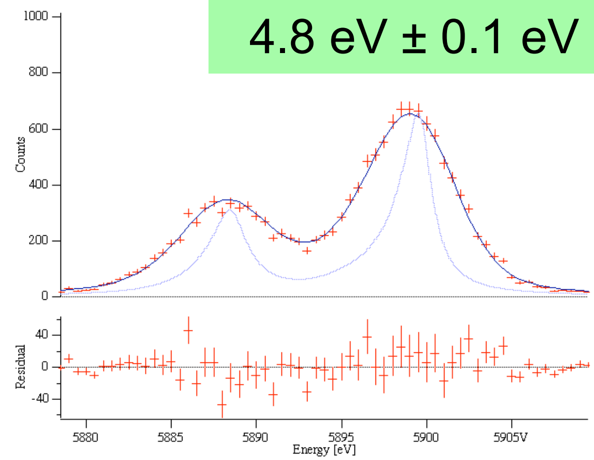


Suzaku X-ray calorimeter array achieved 7 eV resolution on orbit

Next generation arrays being developed for Constellation-X now approaching mission goals of 2-4 eV

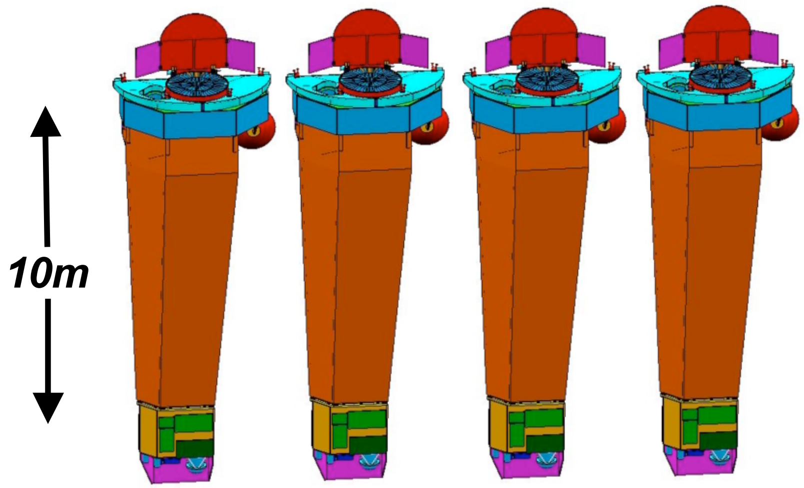


8x8 development TES array for Con-X with 250 μm pixels



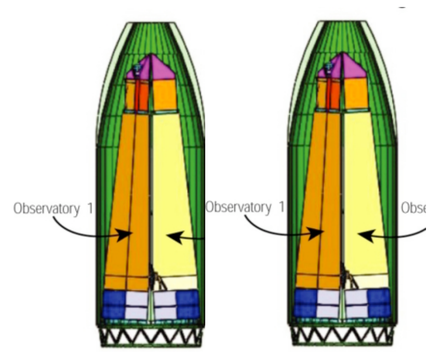
4.8 eV ± 0.1 eV FWHM

Mission Configuration Trade Study



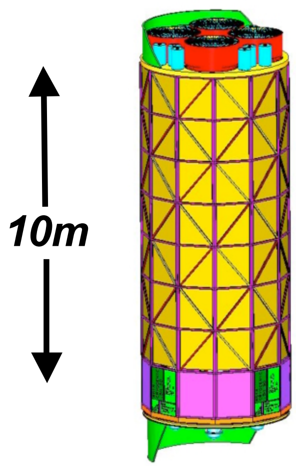
Reference Design

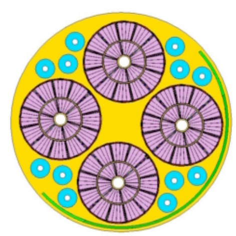
Launched in pairs on 2 Atlas V class launchers

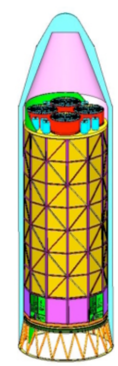


Alternate Design

Single launch on the new Delta IVH launcher







Launch cost saving of ~$120M ***with no loss in science capability***

Technology Solicitation

- ♣Solicitation for Con-X instrument technology development planned for release in spring 2006
  - – Continuation of technology development
  - – Amendment to ROSES NRA
  - – Focus on Constellation-X instrument development for microcalorimeter, gratings and CCDs, hard X-ray detectors and optics
  - – Multi-year grants for technologies currently at technology readiness level 3 to 6
  - – Enable teams to compete for future instrument Announcement of Opportunity

Summary

- The Beyond Einstein mission Constellation-X addresses compelling and high priority science questions
- The observatory opens the window of high throughput, high resolution X-ray spectroscopy
- The technology development continues to make substantial progress towards a launch in about 10 yr

Visit the Constellation-X booth, the posters and see http://constellation.gsfc.nasa.gov for more information!

BEYOND EINSTEIN: From the Big Bang to Black Holes

Constellation X

The Constellation X-Ray Mission

Constellation-X Science

Presented by

Ann Hornschemeier (GSFC)

Deputy Project Scientist

207th Meeting of the American Astronomical Society

January 8 – 12, 2006/Washington, D. C

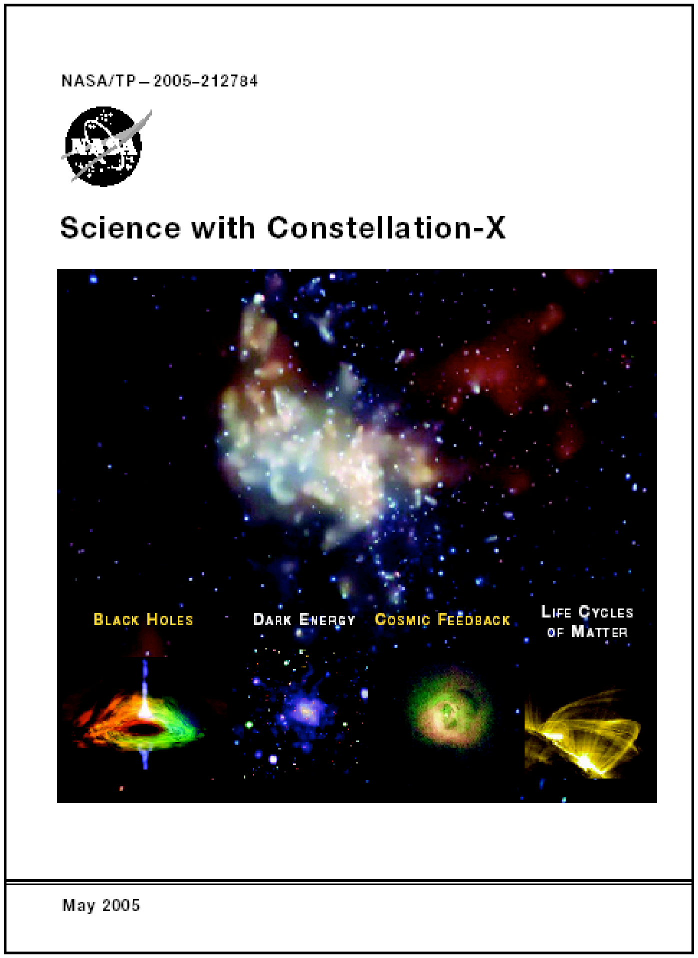
The Constellation-X Science Case Reassessment

- October 2004 through January 2005, >60 scientists met in small groups and produced 13 white papers (100 pages of text)
- Goal: Reassess the Constellation-X science case given progress by Chandra and XMM-Newton over past 5 years
  - Team leaders in this effort:
    - David Alexander (IoA)
    - Jean Cottam (GSFC)
    - Jeremy Drake (CfA)
    - Jack Hughes (Rutgers)
    - Casey Lisse (U Md)
    - Jon Miller (U Mich)
    - Michael Muno (UCLA)
    - Richard Mushotzky (GSFC)
    - Frits Paerels (Columbia)
    - Chris Reynolds (U Md)
    - Gordon Richards (JHU)
    - Michael Shull (Colorado)
    - Randall Smith (JHU/GSFC)
    - David Strickland (JHU)
    - Tod Strohmayer (GSFC)

Result of the Process:

"Science with Constellation-X" booklet

(available at the Con-X booth)



Constellation-X Science Posters (Session 16)

Black Holes and Strong Gravity:

- Miller, J. “Revealing Intermediate Mass Black Holes”
- Reynolds, C. “Probing strong gravity and extreme astrophysics around black holes”

Black Holes and the Growth of Structure:

- Bauer, F. E “The High Redshift Universe”
- Gallagher, S. C. “Cosmic Feedback: Constraining AGN Outflows”
- Levenson, N.A. “Present Observations of Obscured AGN and Future Prospects”
- Nicastro, F. “The Warm-Hot Intergalactic Medium”
- Schindhelm, E. “High resolution x-ray spectroscopic studies of AGN outflows“
- Strickland, D. “ Starburst Galaxies with Constellation-X”

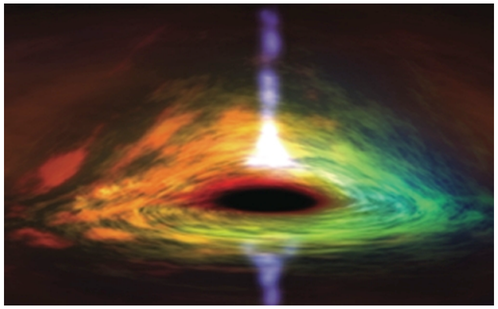
Dark Energy/Dark Matter:

- McNamara, B. R. “Studying Cosmic Feedback in Clusters”
- Rapetti, D. “Probing Dark Energy”
- Vikhlinin, A. “Cosmology with High-Redshift Galaxy Clusters”

Life Cycles of Matter:

- Drake, J. “High Energy Stellar and Protostellar Physics”
- Feigelson, E. “X-rays & Planet Formation”
- Hwang, U. “Constraining the Progenitors and Explosions of Supernova Remnants”
- Sanwal, D. “Neutron Star Equation of State”
- Schulz, N. “X-Ray Surveys of Interstellar Media”
- Smith, R. High-Resolution Spectroscopy of the Diffuse ISM”

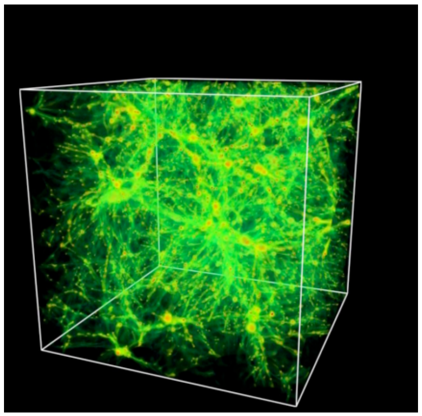
Constellation-X Science Objectives



Black Holes

Observe hot matter spiraling into **Black Holes** to test the effects of General Relativity

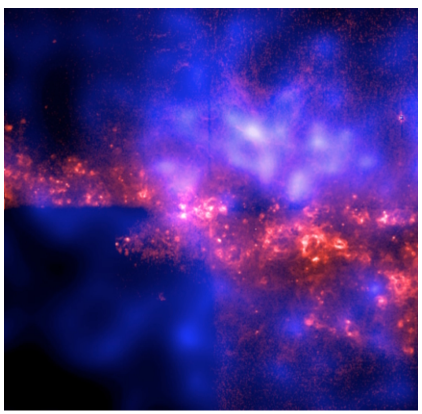
Trace their **evolution with cosmic time**, their contribution to the energy output of the Universe and their effect on galaxy formation



Dark Matter and Dark Energy

Use clusters of galaxies to trace the locations of **Dark Matter** and as independent probes to constrain the amount and evolution of **Dark Energy**

Search for the **missing baryonic matter** in the Cosmic Web



Cycles of Matter and Energy

Study dynamics of **Cosmic Feedback**

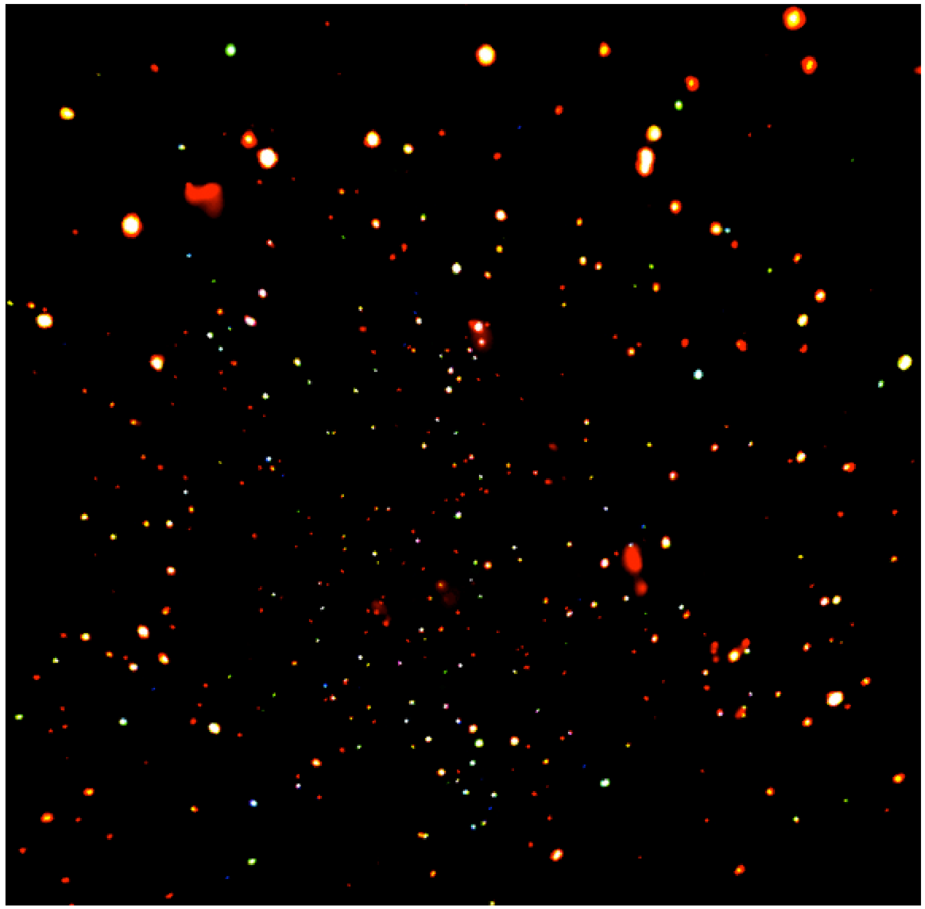
Creation of the elements in **supernovae**, The equation of state of **neutron stars, Stellar activity, proto-planetary systems** and X-rays from **solar system objects**

The Chandra Deep Fields

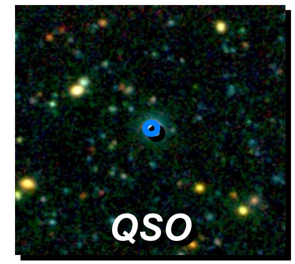
Chandra has resolved the X-ray background into active galactic nuclei (AGN) with a space density of a few thousand per sq deg

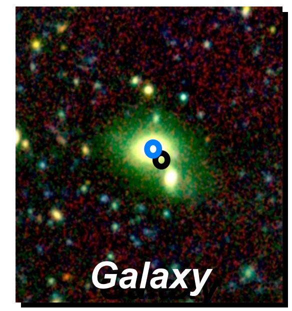
- ♣ Constellation-X will gather high-resolution X-ray spectra of the elusive optically faint X-ray sources

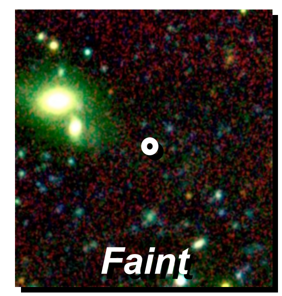
- ♣ Chandra deep surveys have the sensitivity to detect AGN up to z~8



2 Megasecond Observation of the CDF-N (Alexander et al. 2003)





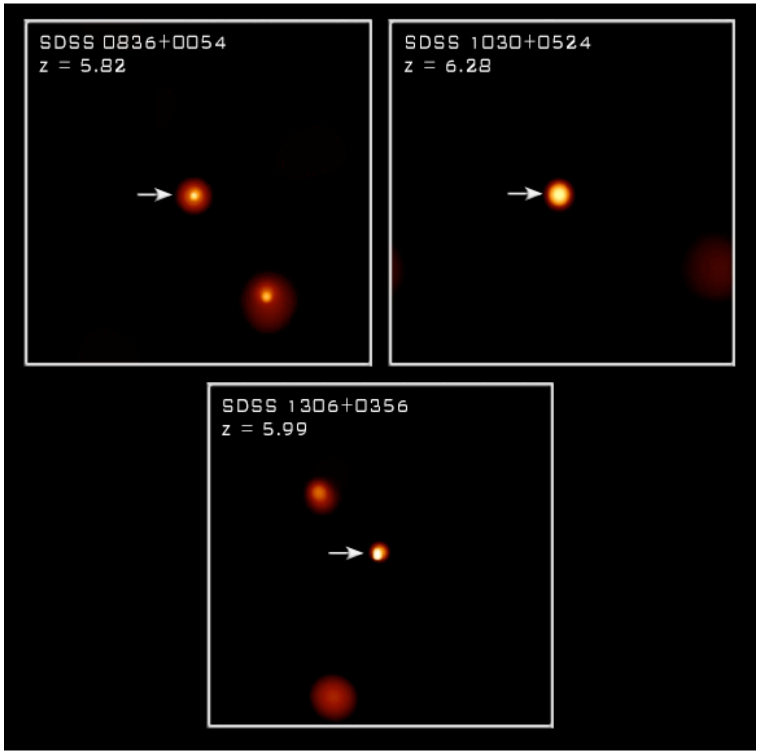


Chandra sources identified with mix of active galaxies and normal galaxies, many are optically faint and unidentified

X-ray Detections of High Redshift QSOs

Chandra has detected X-ray emission from three high redshift quasars at z ~ 6 found in the Sloan Digital Sky survey

Flux of 2-10 x 10^{-15} erg cm^{-2} s^{-1} beyond grasp of XMM-Newton, Chandra or Astro-E2 high resolution spectrometers, but within the capabilities of Constellation-X to obtain high quality spectra



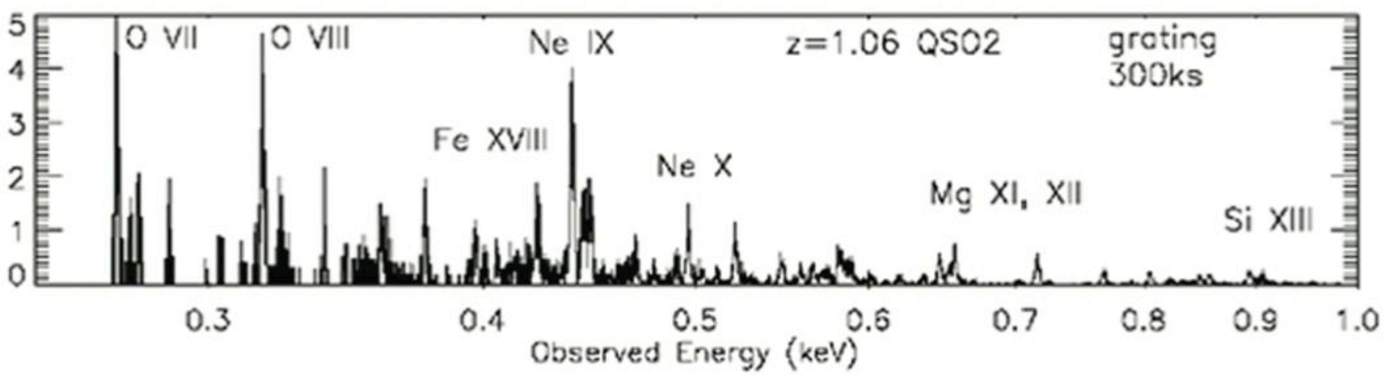
High resolution spectroscopy enables study of the evolution of black holes with redshift and probe the intergalactic medium of the early universe

Black Holes and the Cosmic X-ray Background

- Large fraction of the background identified with moderate-redshift (1 < z < 3) AGN (e.g., Barger et al. 2003)
- Constellation-X will provide detailed spectroscopic IDs

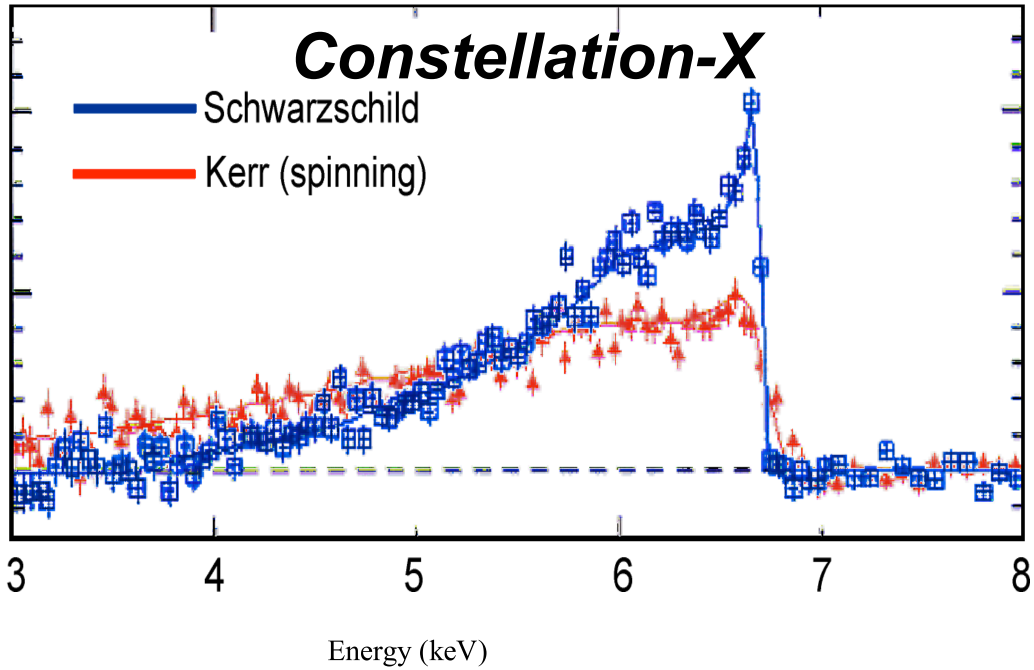
Posters 16.10 (Bauer) and 16.05 (Levenson)

Con-X simulations of faint z=1.06 "Type II QSO"



- Near the background peak energy (20-50 keV) only 3% is resolved (Krivonos et al. 2005)
- Constellation-X will have unprecedented imaging capability at 10-40 keV will resolve a significant fraction of the hard X-ray background

Constellation-X, Black Holes and Strong Gravity



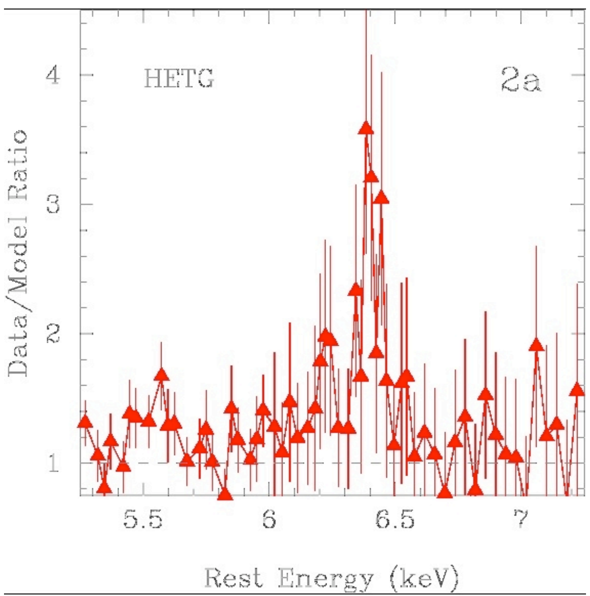
Posters 16.01 (Miller) and 16.02 (Reynolds)

Constellation-X will probe close to the event horizon with 100 times better sensitivity to:

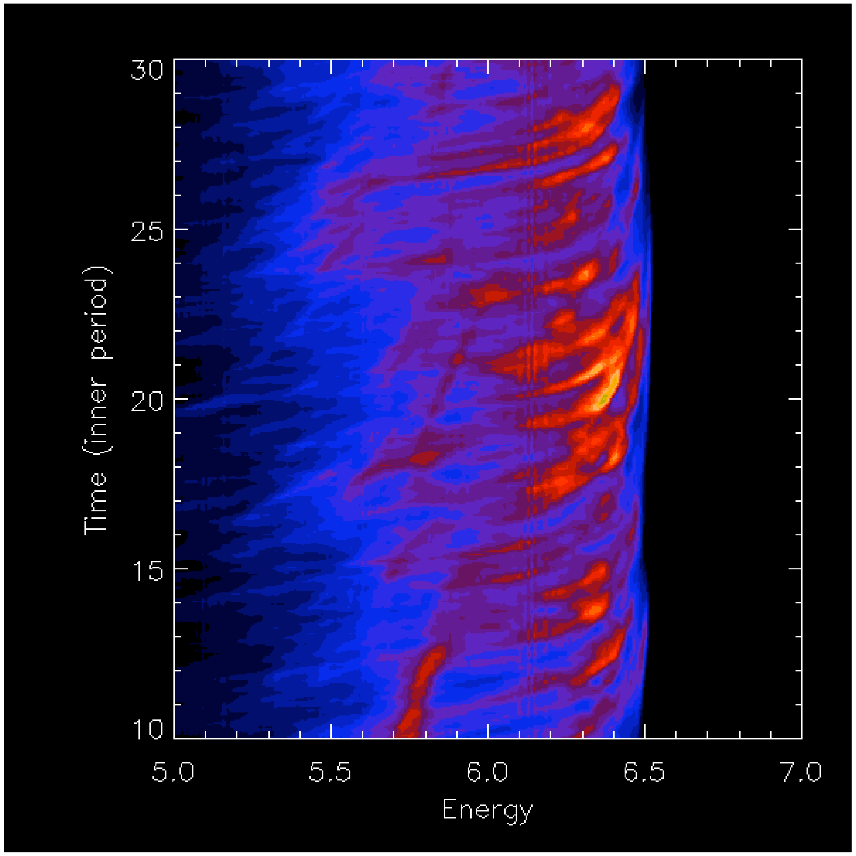
- Observe iron profile from the vicinity of the event horizon where strong gravity effects of General Relativity can be observed
- Use Line profile to determine black hole spin
- Reverberation analysis to determine black hole mass
- Investigate evolution of black hole properties (spin and mass) over a wide range of luminosity and redshift

Iron Line Variability

- Constellation-X will allow detailed study of line variability
- See effects of non-axisymmetric structure orbiting in disk
  - Follow dynamics of individual “blobs” in disk
  - Quantitative test of orbital dynamics in strong gravity regime



Chandra-HETG data on NGC3516 (Turner et al. 2002)

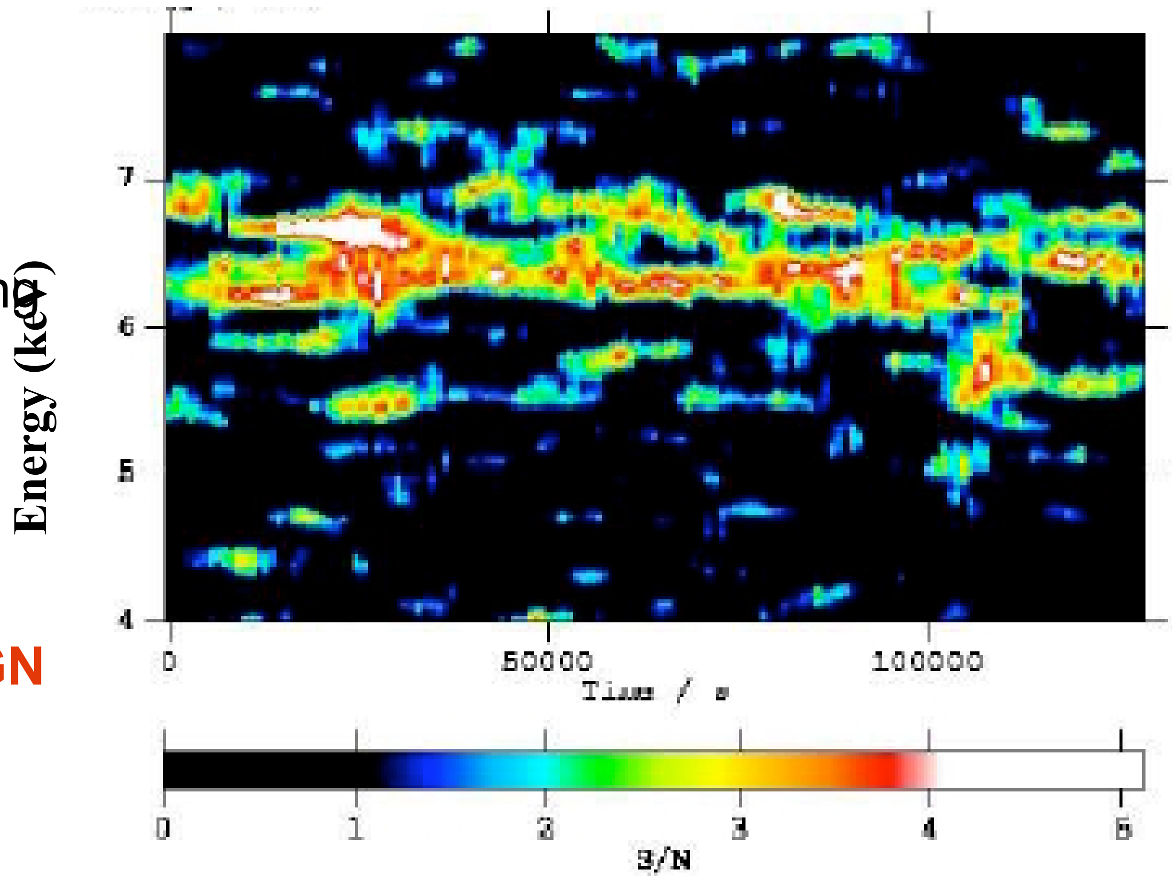


Armitage & Reynolds (2003)

Evidence for non-axisymmetric structure may already have been seen by Chandra and XMM-Newton… Constellation-X area needed to confirm and utilize as GR probes

Fe Kα: Accretion Disk Structure

- Fe K fluorescence from surface layers of thin, Keplerian accretion disk
- Chandra/XMM ◊ beginning to probe structure on orbital/sub-orbital timescales in outskirts of accretion disk
- **Con-X will do the same for ~100-200 nearby AGN**



XMM-Newton obs. of Mrk 766

Credit: Turner et al. (2005; astro-ph/0506223)

Constellation-X constraints on Cosmology from observations of Clusters

Constellation-X will derive cosmological parameters using (at least) three different techniques:

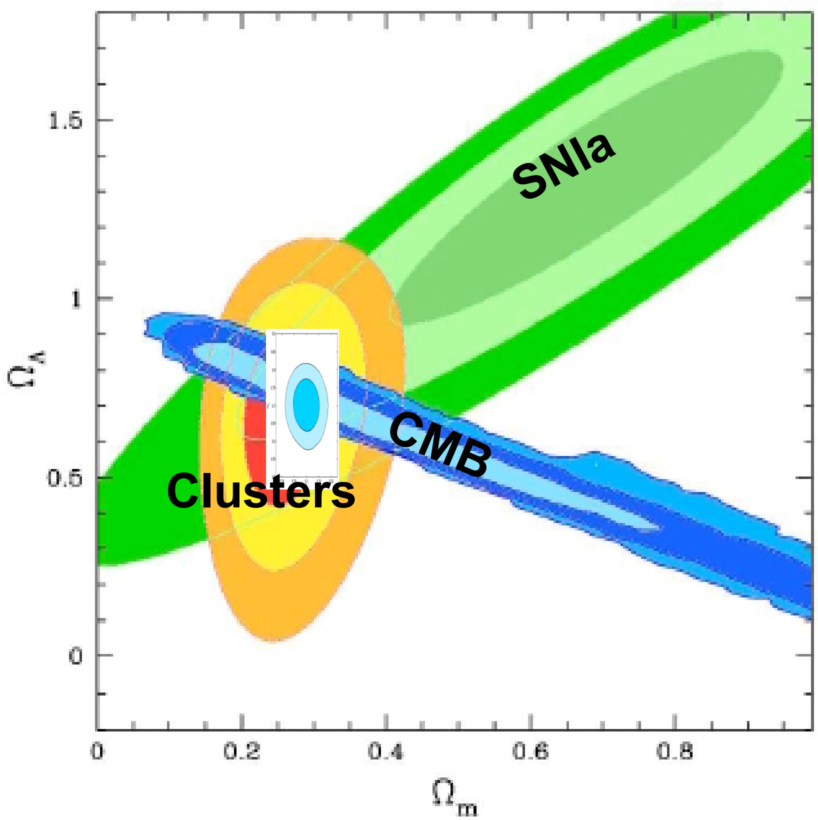
1. In combination with microwave background measurements the Sunyaev-Zeldovich technique to measure absolute distances

2. Using the gas mass fraction in clusters as a “standard candle”

3. Measuring the evolution of the cluster parameters and mass function with redshift

Cosmological Parameters with Constellation-X

(Allen et al. 2005)



See also Posters 16.03 (Rapetti) and 16.17 (Vikhlinin)

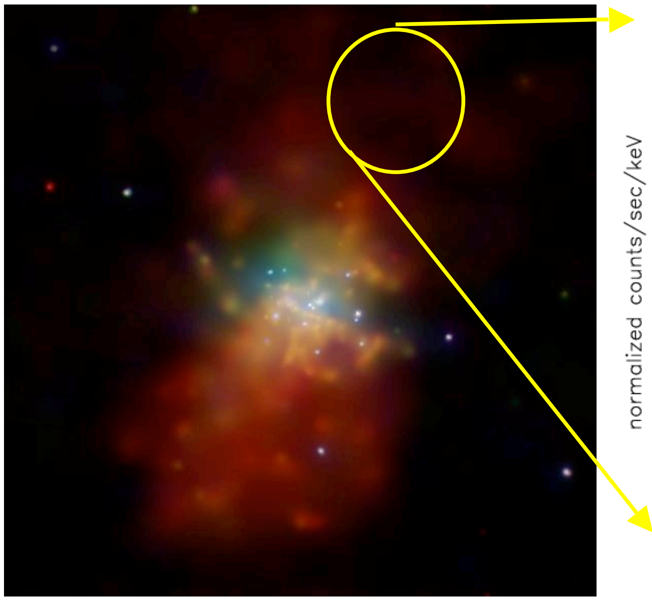
- ♣ Constellation-X effective area critical to study large sample of clusters
- ♣ A large snapshot survey followed by deeper spectroscopic observations of relaxed clusters will achieve f_{gas} measurements to better than 5% for individual clusters:
  - Corresponds to Ω_M=0.300±0.007, Ω_Λ=0.700±0.047
  - For flat evolving DE model,

    w_0 = -1.00±0.15, w' = 0.00±0.27

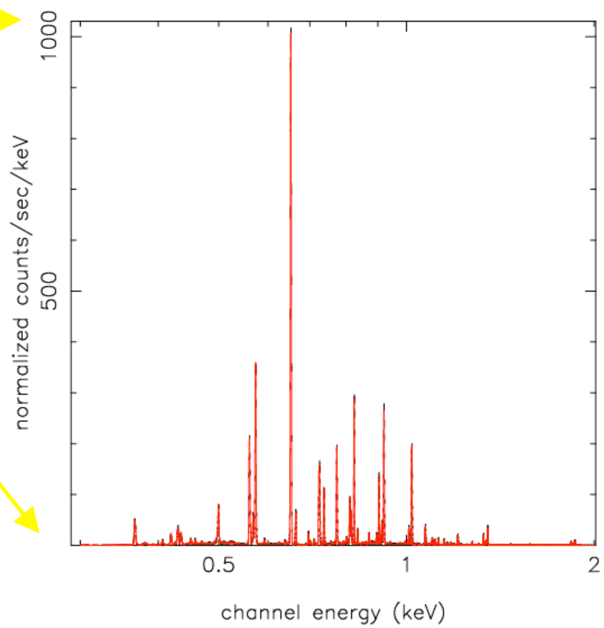
Constraints are similar & complementary to SN Ia studies

Supernova (Stellar) feedback Wind plasma diagnostics (D. Strickland, JHU)

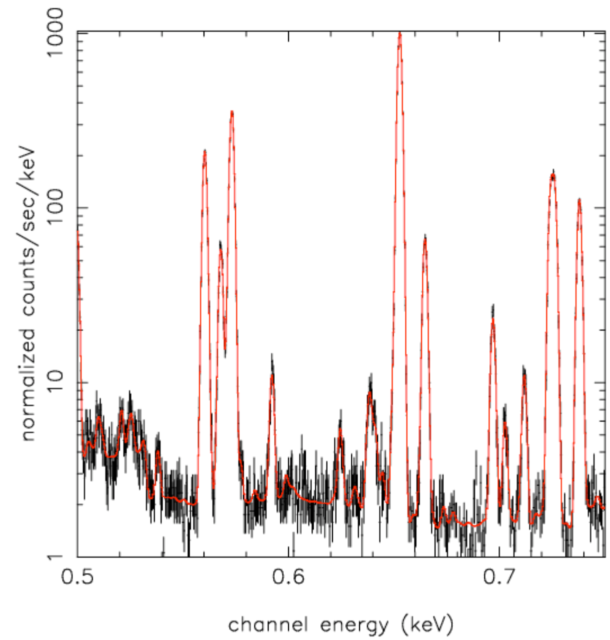
Poster 16.06 (Strickland)



M82 Chandra central 5x5 kpc
0.3-1.1 keV
1.1-2.8 keV
2.8-9.0 keV



Simulated 20 ks Constellation-X northern halo observation, 0.3-2.0 keV



O VII and O VIII region. Well resolved triplet, high S/N in continuum.

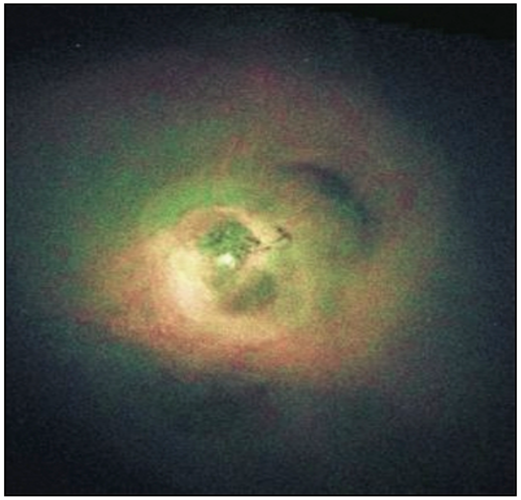
With calorimeter ~2-eV resolution at 1keV we can determine temperatures, densities, and metallicities accurately in many extended winds (not just M82)

Black Holes and Cosmic Feedback

Large scale-structure simulations require AGN feedback to regulate the growth of massive galaxies (e.g., Di Matteo et al. 2005, Croton et al. 2005)

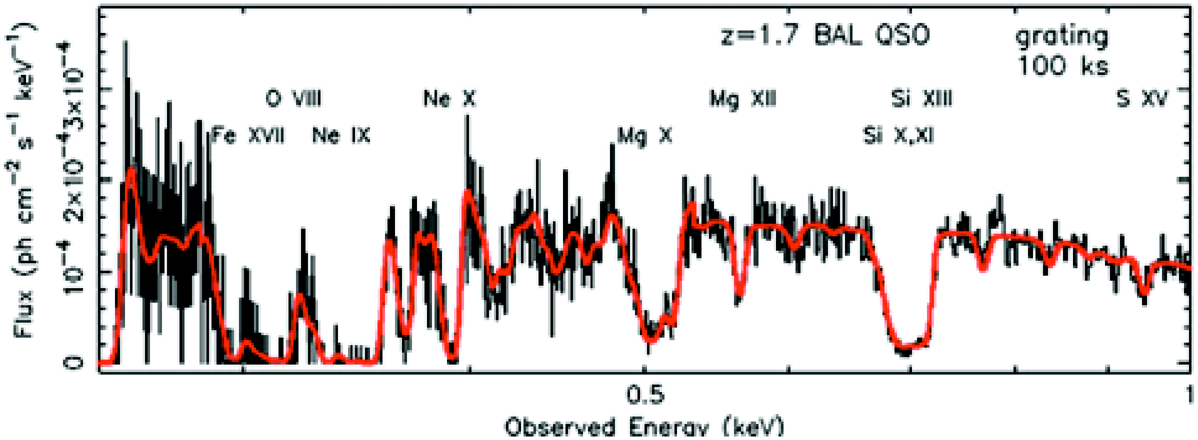
♣ Con-X's non-dispersive X-ray spectroscopy required to probe hot plasma in cluster cores (Begelman et al. 2003, 2005)

Perseus Cluster of Galaxies (Chandra image)



♣ Con-X will reach the powerful AGN outflows in the quasar epoch (1<z<4)

Con-X simulation of BAL QSO (S.Gallagher, UCLA)



Posters 16.08 (Gallagher) and 16.09 (Schindhelm)

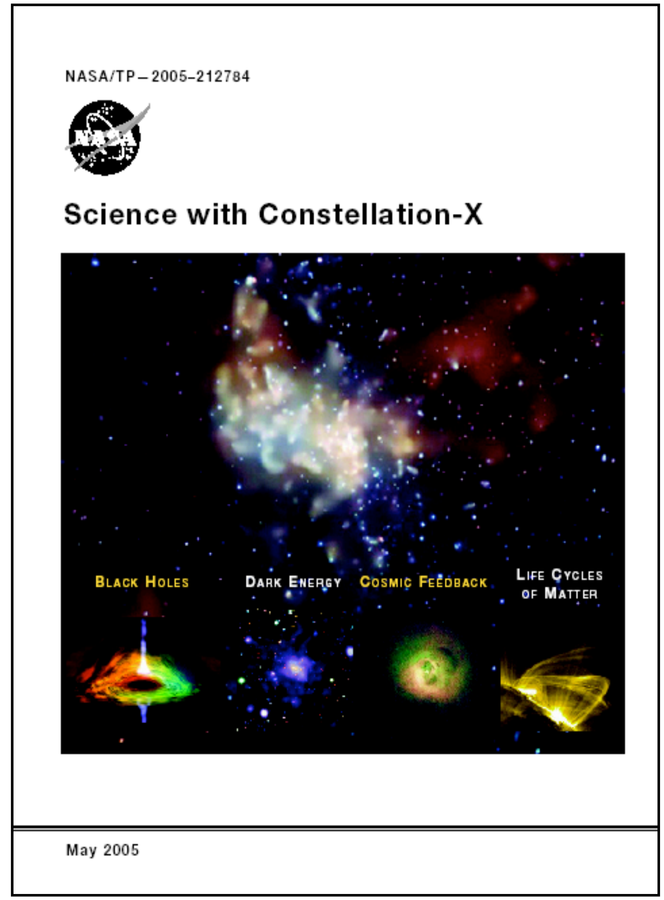
Summary

- ♣ The Constellation-X science case remains compelling, more details are available in the “Science with Constellation-X” booklet

- ♣ Please visit poster session 16: Example Constellation-X Science

- ♣ See also the Constellation-X web site:

http://constellation.gsfc.nasa.gov



BEYOND EINSTEIN: From the Big Bang to Black Holes

Constellation X

The Constellation X-Ray Mission

Technology Report

Presented by

Michael Garcia (SAO)

Science Lead

207th Meeting of the American Astronomical Society
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Con-X Technology Posters (Session 12)

Spectroscopy X-ray Telescope

- Zhang, W.W., "Lightweight X-ray Mirrors for the Constellation-X Mission "
- Reid, P.B., "Stray Light Shielding for Formation Flying X-ray Telescopes"

X-ray Microcalorimeter Spectrometer

- Eguchi, H., "Properties of Vapor-Deposited Au:Er Films for Metallic Magnetic Calorimeters"
- Irwin, K.D., "Multiplexed x-ray microcalorimeters with improved energy resolution for Constellation-X"
- Kelley, R., "Requirements, Goals and Challenges for an X-Ray Microcalorimeter Spectrometer on the Constellation-X Observatory
- Kilbourne, C.A., "High-density arrays of x-ray microcalorimeters for Constellation-X"
- Porter, S.F., "The development of high resolution silicon x-ray microcalorimeters"
- Silver, E.H., "Advances in NTD Germanium-Based Microcalorimeters For Soft and Hard X-Ray Spectroscopy on Constellation X"

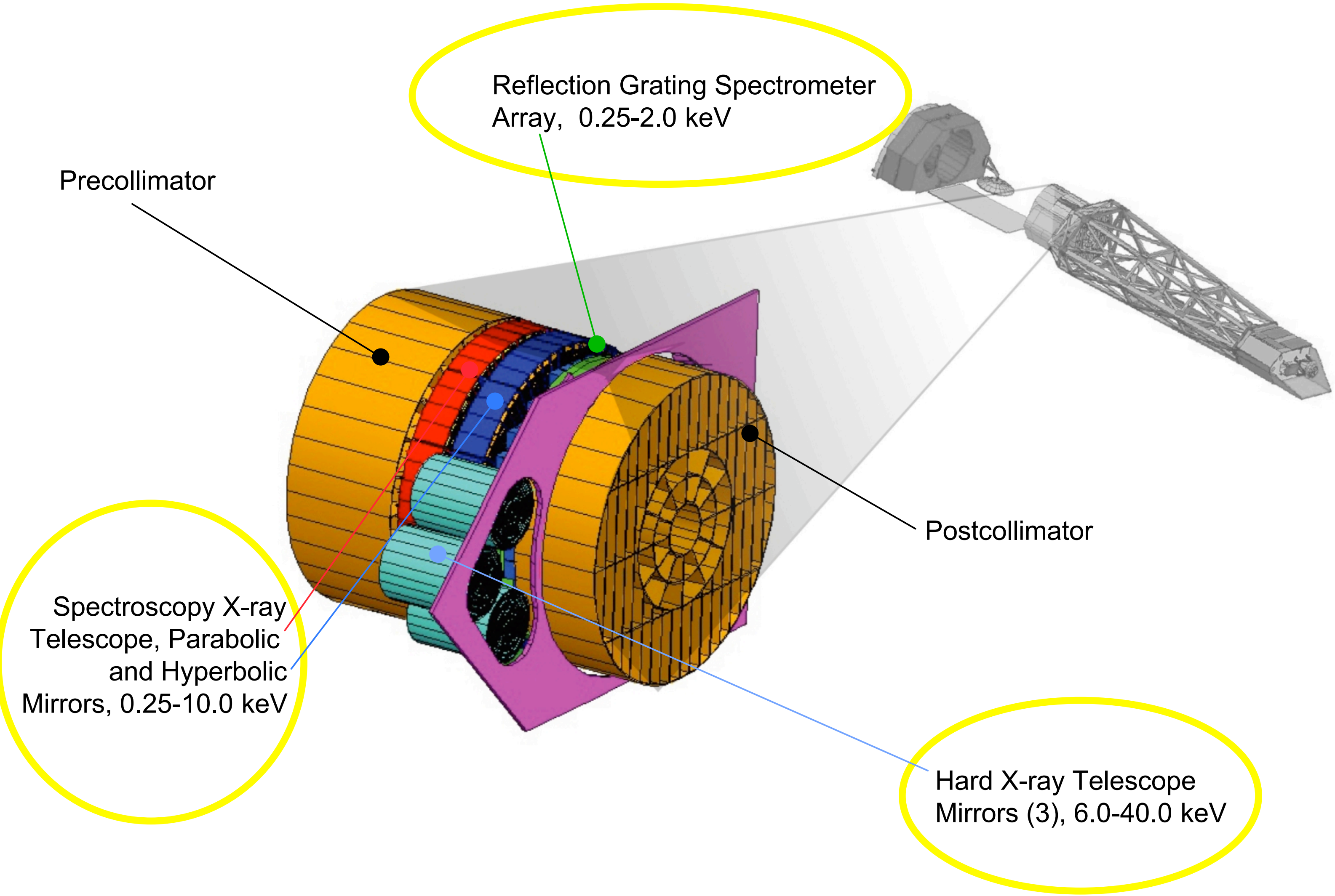
Hard X-ray Telescope

- Gorenstein, P., "The Con-X Hard X-Ray Telescope and its angular resolution"
- Hailey, C., "Segmented Glass Optics and the Hard X-ray Telescope on Constellation-X: Progress and Prospects"
- Romaine, S., "Development of Prototype Nickel Optic for the Constellation-X Hard X-Ray Telescope"

Reflection Grating Spectrometer

- Flanagan, K., "Highlights of Constellation-X Reflection Grating Spectrometer Technology Development"
- Heilmann, R., "Soft X-ray Reflection Grating Technology Development for Constellation-X"
- Seely, J.F., "Efficiency of a Grazing Incidence Off-Plane Grating in the Soft X-Ray Region"
- Ricker, G.R., "Event Driven X-ray CCD Detector Arrays for the Reflection Grating Spectrometer on the Constellation-X Mission"

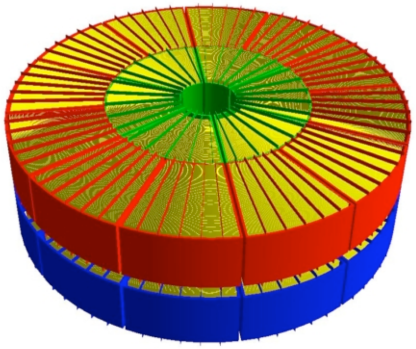
Constellation-X Observatory — Optics Module



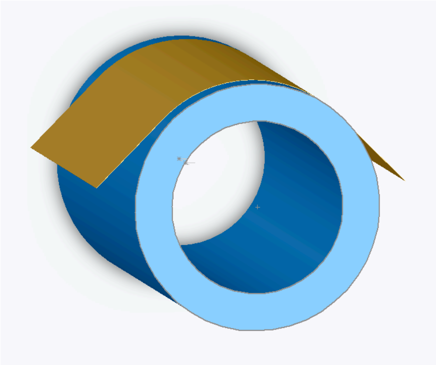
Spectroscopy X-ray Telescope

- ♣ Mirror Design
  - – Wolter-1, true P/H pairs
  - – Segments: 60°, 30°
- ♣ Highly Nested, Low Mass, < 12.5'' HPD
  - – Segmented technology (Suzaku), thin glass, meets mass requirement
  - – Requires 10x improvement in HPD and 4x increase in diameter
- ♣ Mirror segment fabrication process
  - – Thin, thermally formed glass substrates on P/H forming mandrels
  - – Thin gold reflectors on replication mandrels
  - – Gold reflector epoxied to glass P/H

SXT Mirror

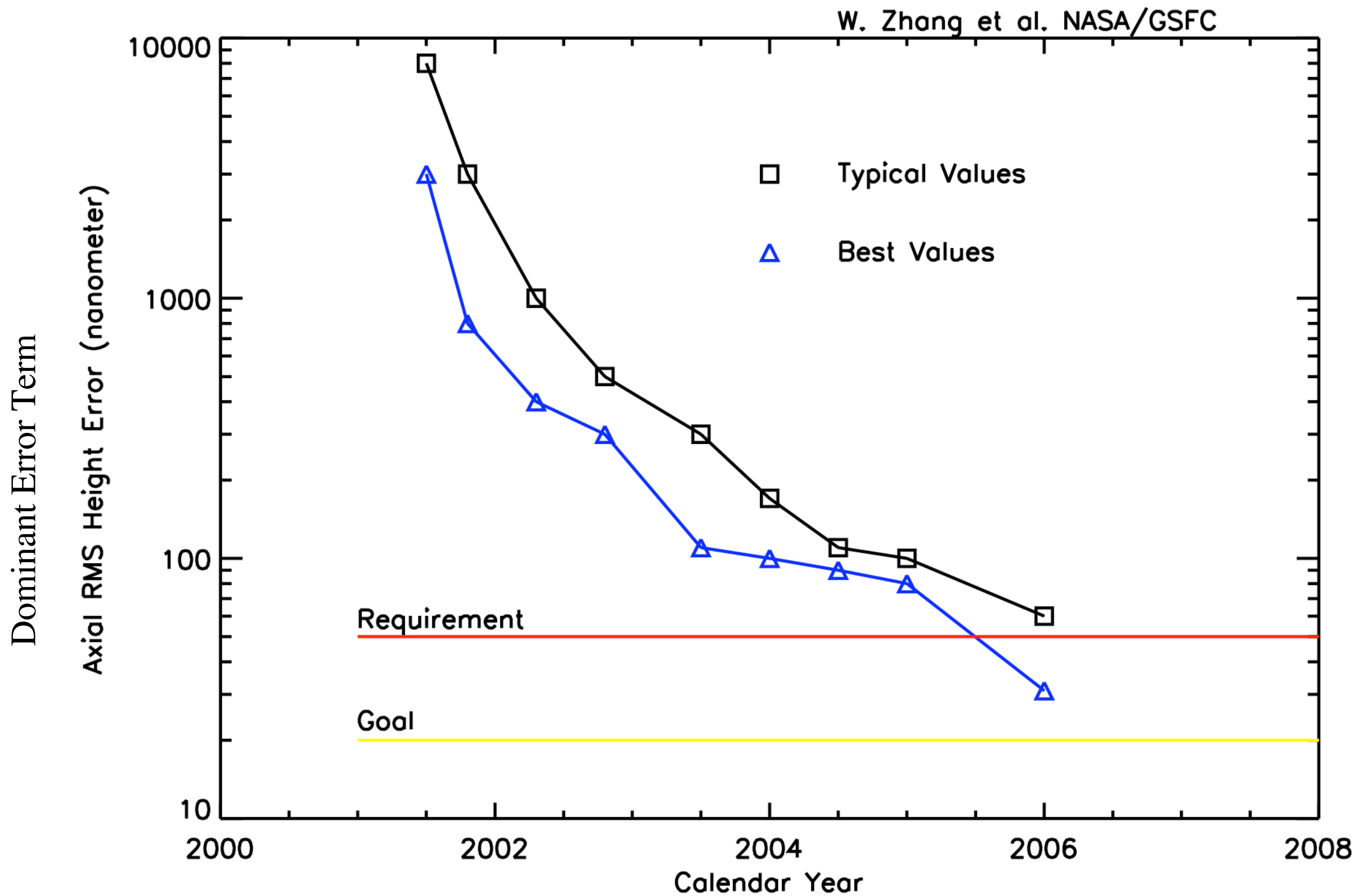


Glass Substrate Fabrication



Gold Reflector

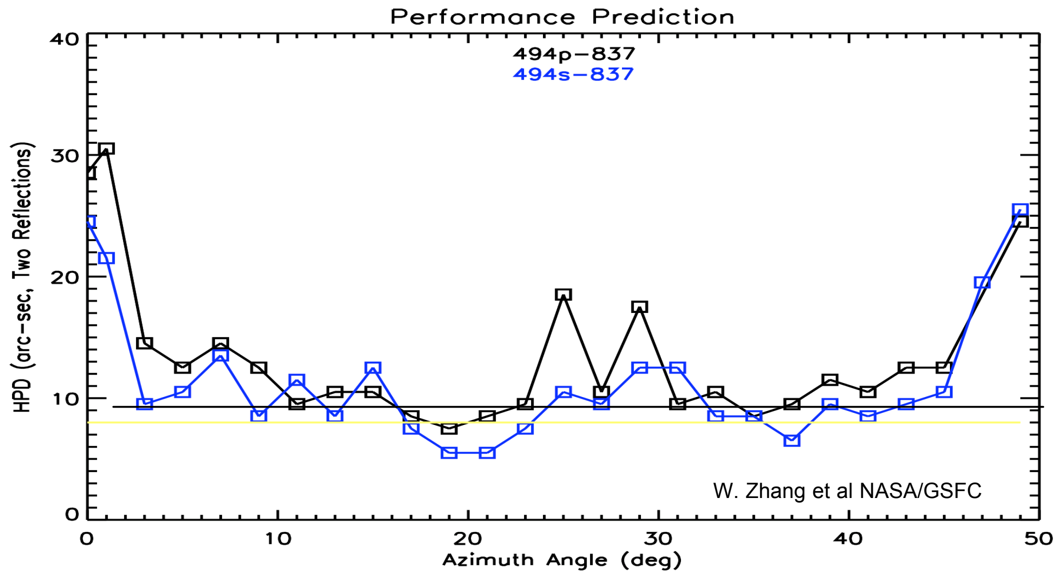
Spectroscopy X-ray Telescope Reflector Progress



Spectroscopy X-ray Telescope Reflector Progress Cont'd

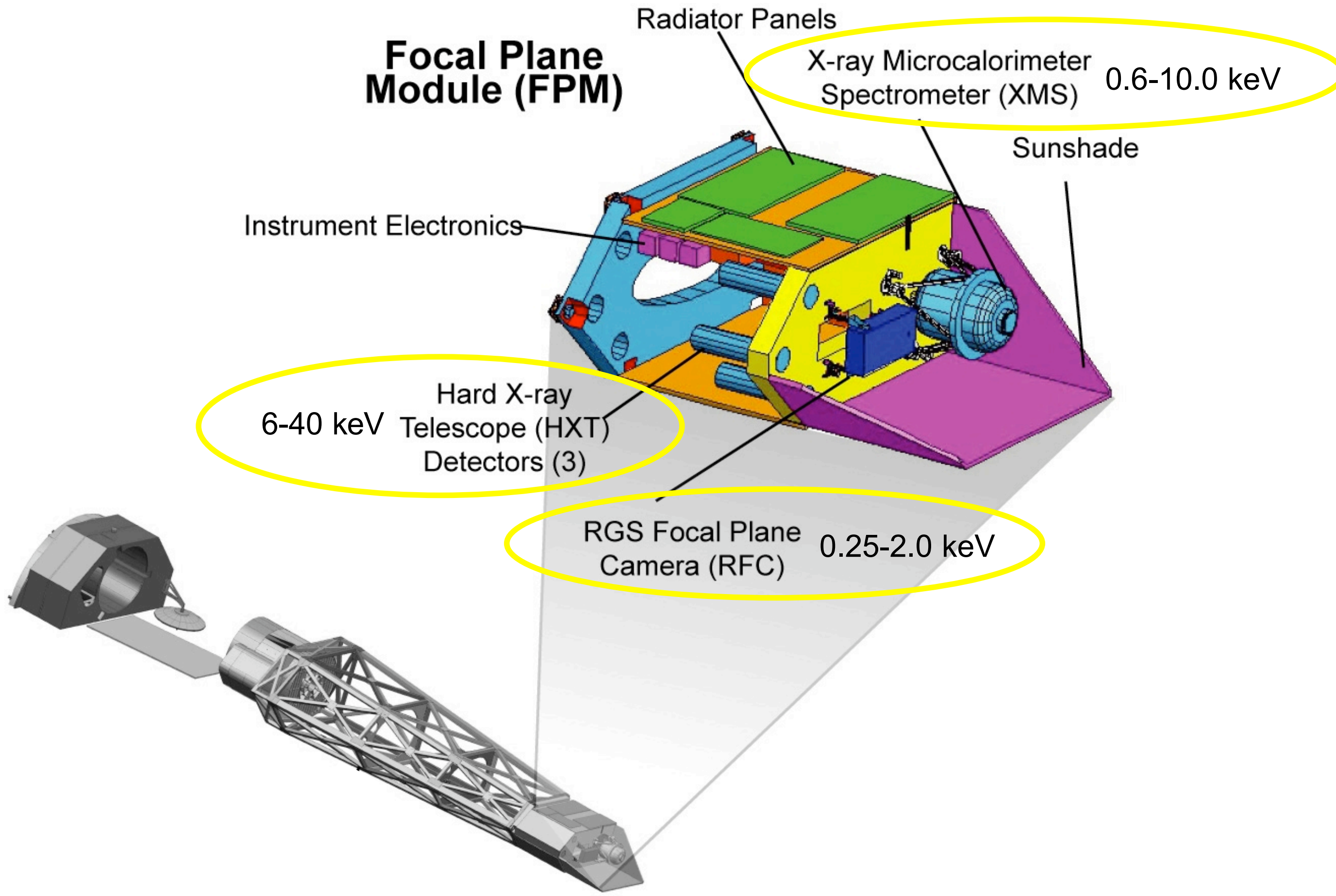
- MANY reflectors within factor of 2 of requirement, improvements continuing
- BEST pair of glass substrates near requirement *w/o epoxy replication*

BEST glass substrates
Prediction @ 1.24keV
Axial rms only:
8" allocated
(12.5" total HPD PSF)

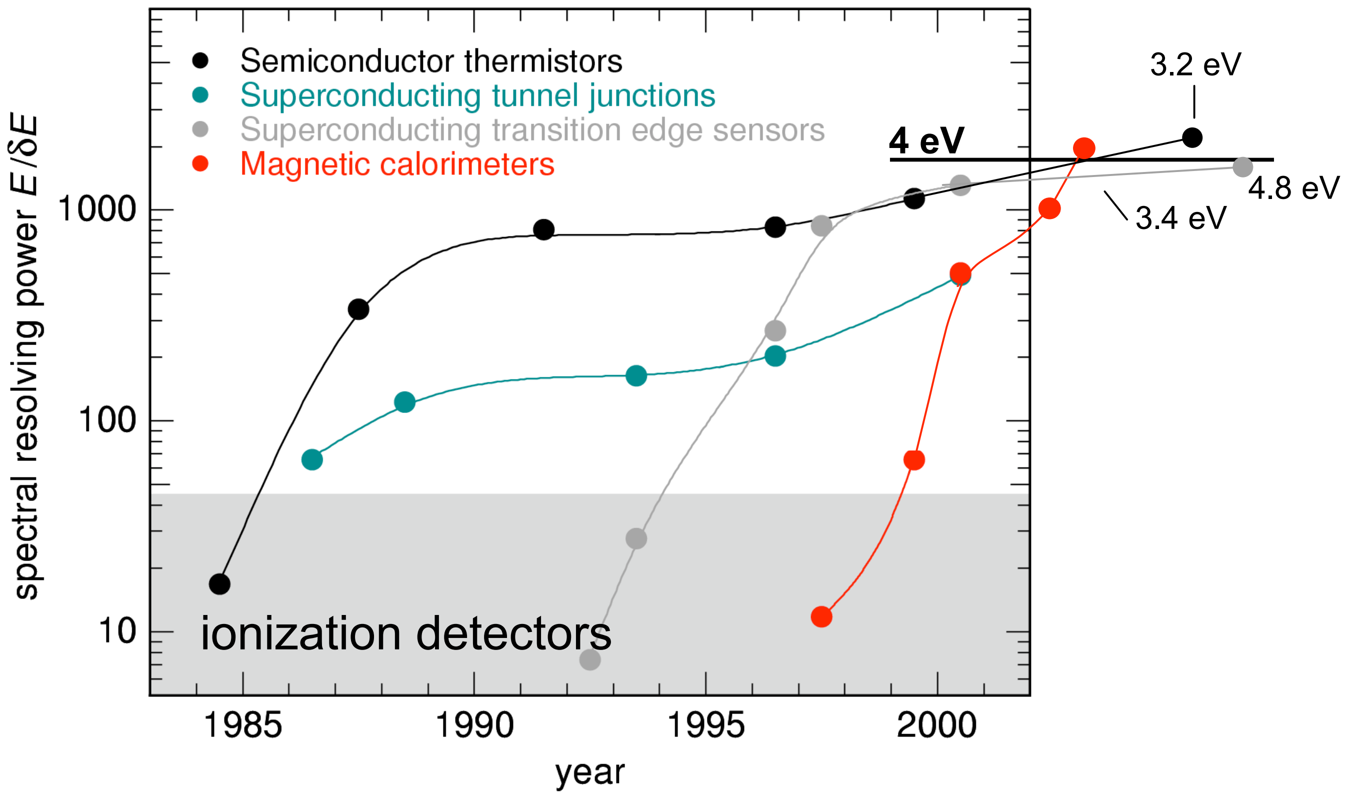


- Some evidence mandrel quality limits substrate performance, but still under investigation
- Improved substrate mandrels may eliminate epoxy replication process: no replication mandrels, process simplification, faster schedule
- Poster 12.10, Zhang et al

Focal Plane Module



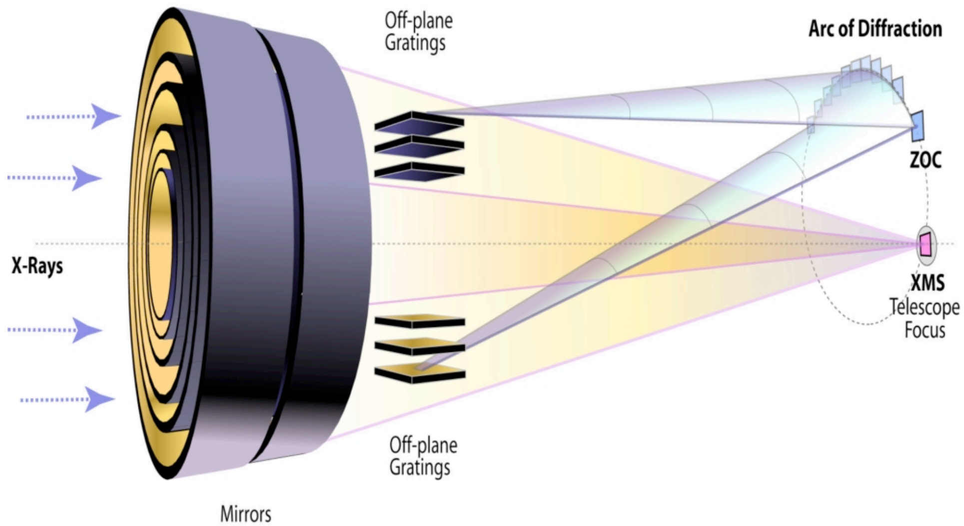
Micro-calorimeter Progress: ΔE@6 keV



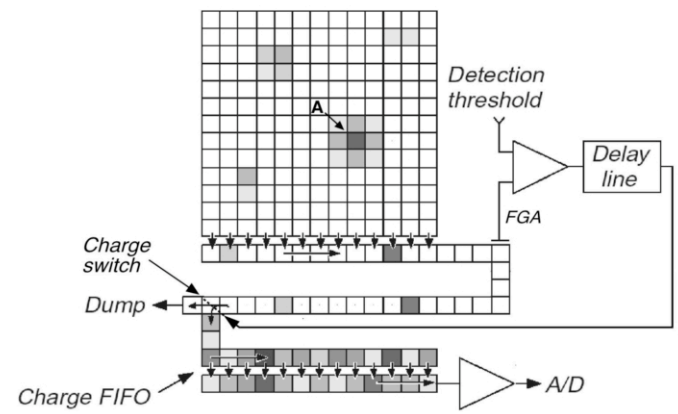
Posters 12.04 Kelley et al, **12.05 Irwin et al,** **12.06 Silver et al,** 12.07 Kilbourne et al, 12.08 Porter et al, **12.09 Eguchi et al**

Reflection Grating Spectrometer Status

0.25-2.0 keV, E/dE>300 <1keV



(Geometry is highly exaggerated)



Event-Driven CCD

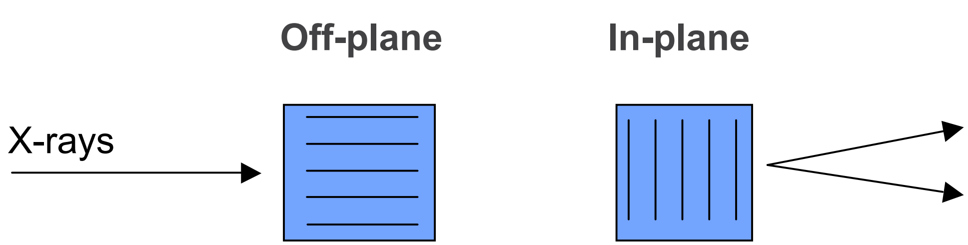
Pixels are non-destructively sensed, and only those with signal charge are saved and digitized

High speed: 100 x Chandra/ACIS (reduced pileup, thinner OBF, higher low E QE)

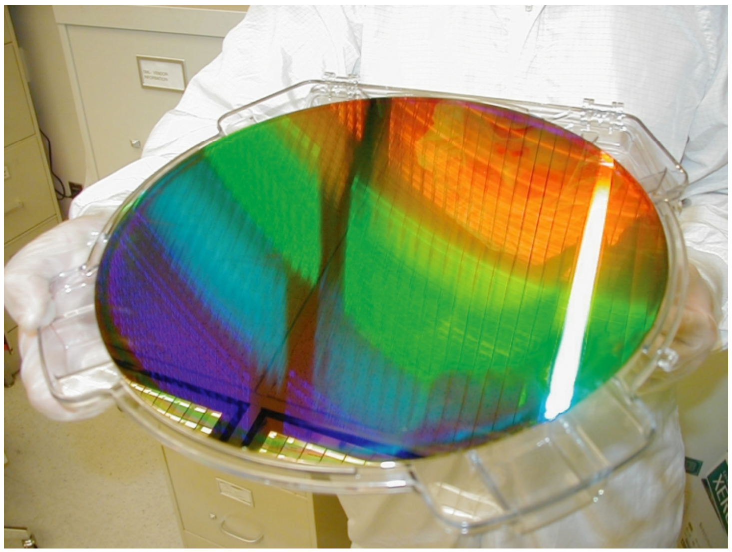
- Devices Fabricated

- Readout Electronics testing underway

Grating Ruling Geometry:



Reflection Grating Spectrometer Status Cont'd



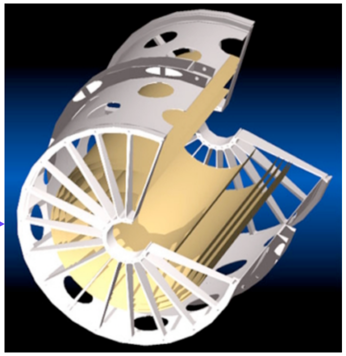
Full size achieved
with Scanning Beam Interference Lithography
(small one at Con-X Booth!)

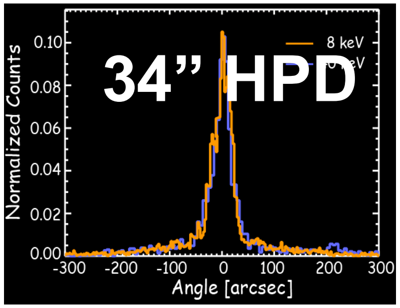
- See Posters!
  - 12.01, Flanagan et al, RGS Development
  - 12.02, Seely et al, OPG Efficiency
  - 12.03, Ricker et al, EDCCD
  - 12.15, Heilmann et al, RG Development

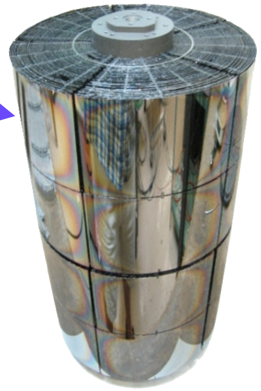
Hard X-ray Telescope Progress

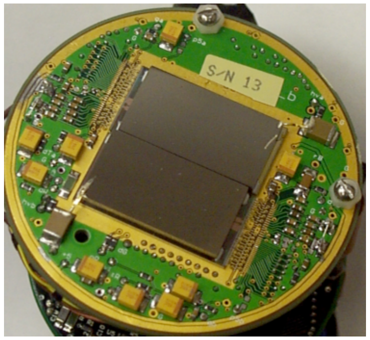
Require >1500cm^2 6-40 keV, < 60'' HPD, E/dE>10

- Two possible Technologies (both multilayered):
  - Full Shell Ni Mirrors
    - » Balloon Program (HERO)
    - » Demonstrated 28'' HPD full shell
  - Segmented Glass Mirrors
    - » Balloon Program (HEFT)
    - » Demonstrated 34'' HPD segment
- Both technologies at Goal 20'' HPD
- Existing CdZnTe technology meets requirements
  - Flown in HEFT ballon, NuSTAR SMEX 2009
  - CdTe may have higher yield, radiation tolerance
  - Active CsI shielding at L2 being optimized
- Posters 12.11 Hailey et al, 12.12 Romaine et al, 12.13 Gorenstein et al









CdZnTe Vibration Test

TECHNOLOGY UPDATE SUMMARY

- Spectroscopy X-ray Telescope:
  - Epoxy replicas consistently within 2 of requirements, improvements continue
  - Best substrates meet (partial) requirements, possible process simplification
- X-ray Microcalorimeter Spectrometer
  - 4eV requirement met for non flight like arrays
  - Flight like arrays close to requirement and improving
- Reflection Grating Spectrometer
  - Off-Plane Grating technology looks promising
  - Event Driven CCDs for readout
- Hard X-ray Telescope
  - Telescope(s) meeting requirements, goals being approached
  - Detectors meet requirements, optimization for L2 being pursued

In closing

- ♣ We have reassessed the Constellation-X science case in 2005 and find it is as compelling as ever
- ♣ The technology development continues to make substantial progress towards a launch in about 10 yr
- ♣ We invite members of the community to attend the public Facility Science Team meeting in Cambridge, MA February 15-16, 2006
- ♣ Please visit these two poster sessions TODAY:
  - Session 12: Con-X Instruments & Optics
  - Session 16: Example Constellation-X Science
- ♣ Visit Constellation-X booth in the main hall and the web site:

http://constellation.gsfc.nasa.gov